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DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

THE ELECTRICAL SECTION OF THE BUREAU OF MINES

ITS PURPOSE AND EQUIPMENT

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BY

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THE ELECTRICAL SECTION OF THE BUREAU OF MINES, ITS PURPOSE AND EQUIPMENT.

By H. H. Clark.

INTRODUCTION.

There is a distinct branch of electrical engineering in connection with the equipment of mines. The conditions in mines are very different from those on the surface. Not only is it more difficult to install and properly maintain electrical equipment underground, but, unless suitable precautions are observed, the presence of such equipment in mines adds danger to a calling already hazardous.

The electrical section of the Bureau of Mines is particularly concerned with the problem of safeguarding life and property from the dangers which attend the use of electricity underground. The following pages discuss some of the features of the problem, outline the purpose and scope of the investigations of this section of the bureau, and describe the work that it has undertaken.

The bureau appreciates that the suggestions of the inspection departments of the various States and the cooperation of all those who use or manufacture electrical mining equipment will be invaluable in attacking this problem, and is issuing this bulletin to call attention to the work and to invite suggestions with regard to it. Correspondence should be addressed to the Director of the Bureau of Mines, Washington, D. C.

UNDERGROUND ELECTRICAL EQUIPMENT AND CONDITIONS.

ELECTRICAL EQUIPMENT.

Electricity is used underground in mines for haulage, lighting, driving pumps, fans, drills, coal-cutting machines, and hoists, for detonating explosives, and for signaling.

Both direct current and alternating current are used, the former much more extensively than the latter. Direct current is distributed at potentials up to 600 volts wherever power is used. Alternating current is distributed at over 2,000 volts and is usually carried only a short distance underground to serve high-voltage motors or transformers operating motor-generator sets or rotary converters.

Electric haulage is operated principally from trolley wires at 250 or 500 volts. The trolley wire is necessarily bare, and in low coal is dangerously near the heads of persons in the same entry with it. Lighting circuits are often connected between the trolley wire and earth, with the lamps in series. Stationary motors are often connected between the trolley wire and earth. Machine wires are frequently bare up to the point of connection with the trailing cables.

Explosives are detonated from batteries (storage or primary), from magneto generators (frequently referred to as batteries), from power circuits, and from separate generators used only for detonating. Signals, which include lights, bells, and telephones, are operated principally from primary batteries.

CONDITIONS SURROUNDING EQUIPMENT.

Underground equipment is exposed to falls of roof, coal and rock, that are sufficient to wreck installations of the best character. The acid waters and the dampness in mines make the insulation problem difficult.

The fact that the need of electric service at many points underground is only temporary limits economical investment in equipment.

The problem of safeguarding life is rendered still more difficult by the fact that many of the underground workers do not appreciate the dangerous character of electricity and ignore the rules made for their protection.

The temptation to install electrical equipment in coal mines in a temporary and improper manner is increased by the fact that coal, especially dry coal, is not a good conductor of electricity, and wires may sometimes come in contact with the coal without trouble resulting. A machine wire supported upon wooden pegs driven into the coal may never give trouble; and it would be hard to convince a man whose only experience had been with such installations that to thus support a wire is not good practice.

In this connection it is probable that electrical practice in mines would be generally improved if more of the mine electricians were familiar with the best installation methods.

DANGERS FROM ELECTRICAL EQUIPMENT.

The three principal dangers connected with the use of electrical equipment in mines are as follows: The danger from electric shock, the danger from explosions caused by electricity, and the danger from fire started by electricity.

The chief sources of danger from shock are the trolley wire and other bare conductors. Another source is ungrounded equipment that has become charged with electricity through defective insulation or otherwise.

The danger from electrical explosions arises from the occurrence of sparks and arcs in inflammable gas or dust. Sparks of sufficient size to ignite gas may be produced when a motor is started rapidly or operated under heavy load, when a circuit carrying current is opened, or when a circuit becomes grounded. A much larger spark is required to ignite bituminous coal dust, but such dust might be ignited by the opening of a circuit carrying a large current, or by flashes produced by heavy short circuits. The fall of a trolley wire might give both of these conditions.

The danger from fire arises from grounds to coal or in the vicinity of inflammable material, from the flashing of motors under the latter condition, from short circuits, and the burning off of wires carrying heavy currents.

Besides the above-mentioned dangers, the handling of explosives in the vicinity of electricity and the detonation of them by electric means give rise to others.

SAFEGUARDING THE USE OF ELECTRICITY.

The practical solution of the problem of safeguarding the use of electricity in mines will require the adoption of protective measures and of devices that are simple, rugged, "fool proof," and as inexpensive as possible. At the same time both measures and devices must be entirely effective or they will become a menace.

Although it will be necessary to investigate many possible causes of electrical dangers, some are already well known, and the desirability of protection against them is apparent.

There is a field for devices for reducing the danger of shock from the trolley wire and for devices for preventing the ignition of gas by motors, switches, and other circuit-opening apparatus. There is a field for an acid-proof material for insulating wires and cables, and there is room for improvement in the methods of installing electrical equipment underground.

The improvement of electrical conditions underground will doubtless be a gradual development, as has been the case aboveground where advancement in electrical practice has been continuous for many years.

Most mine operators, if not all of them, would be willing to install safer electrical equipment if the market could supply it. Manufacturers are willing to develop especially safeguarded equipment as fast as they see a field for its use. Some of the manufacturers of this country are now developing motors and switches designed to be explosion proof, and the Bureau of Mines has always found manufacturers of electrical apparatus ready to cooperate in its electrical investigations.

THE ELECTRICAL SECTION OF THE BUREAU OF MINES.

PURPOSE AND SCOPE.

The electrical section of the Bureau of Mines was organized in 1909 to investigate the conditions under which electricity is used underground, in order to obtain data that will be of assistance to those State officials who have charge of the regulation and inspection of mines and to all who use or manufacture electrical mining equipment. The section is part of the mining experiment station of the bureau at Pittsburg, Pa.

It is the purpose of the section to attempt to discover the causes of accidents from the use of electricity in mines and to suggest means for the prevention of such accidents; to make tests of the safety of electrical equipment under conditions most conducive to disaster; and to make such tests of a general nature as bear upon the safety of electricity in mines, accidents attributed to electrical causes, etc.

Although the function of the section is to investigate and test rather than to develop, facts that will be of value to those designing equipment are continually being learned in the process of testing and are always at the disposal of interested persons.

Bulletins will be issued from time to time describing the tests made and the results obtained. The section is always ready to discuss, by correspondence or by conference at the Pittsburg station, the problems relating to accidents caused by electricity, the results of tests, or the means and methods of safeguarding underground electrical equipment.

EQUIPMENT.

Direct current is available for testing purposes in any voltage up to 750 volts, and alternating current up to 2,000 volts for power and up to 30,000 volts for high potential tests.

The laboratory is provided with a 6-panel switchboard for the control of transformers, generators, and circuits; a complete equipment of alternating-current and direct-current voltmeters and ammeters; an outfit for measuring insulation resistance up to 80,000 megohms; a 5-kilowatt high potential testing transformer, the voltage of which can be gradually varied up to 30,000 volts; a Wheatstone bridge; rheostats; and miscellaneous tools and supplies.

There are two galleries for testing electrical equipment in the presence of gas. The smaller of these is installed in the laboratory; it consists of a boiler-iron box provided with connections for gas and air, heavy plate-glass observation windows, and openings for relieving the pressure caused by an explosion. A small motor-driven centrifugal fan is used to mix the gas and air and to circulate them through the gallery. Means are provided for predetermining the

percentage of gas in the mixtures used. Tests of electric sparks and of incandescent lamps and small apparatus are made in this gallery.

The larger testing gallery is a tube designed to represent a short section of a mine entry. It is erected outside the laboratory and consists of a cylindrical shell of boiler iron 30 feet long and 10 feet in diameter, laid horizontally upon a concrete bed and partly filled with concrete to form a floor upon which apparatus can be set up for test. At 7½ feet from either end the cylinder can be stopped off with diaphragms of heavy paper, which relieve the pressure from explosions before it becomes dangerously heavy. After the diaphragms are in place the gallery can be entered through a manhole cut in the side of the shell between the heads. Heavy plate-glass windows are set in the sides of the gallery.

A large motor-driven centrifugal fan mixes and circulates the gas and air, and a special device has been developed to indicate the percentage of gas in the mixtures. Tests of explosion-proof motors, explosion-proof switches, and other large apparatus are made in this gallery.

A gallery or testing tube for investigating the ignition of coal dust by electricity is now being designed and will be constructed shortly. This gallery will be similar in most respects to those already described, but will differ in a few details.

Every investigation requires more or less special apparatus, and as new tests are begun new equipment will be procured.

INVESTIGATIONS.

The bureau has made a few preliminary investigations, the most important of which are an investigation as to the danger of gas ignition by the indicators of inclosed fuses, and an investigation as to the danger of gas ignition by incandescent lamps when broken in gaseous atmospheres. The former is reported in detail in this circular; the latter is being continued, and a final report will be made after the completion of more elaborate tests.

INCANDESCENT LAMP TESTS.

The preliminary investigation showed that certain sizes of incandescent lamps, when broken, ignite surrounding explosive mixtures of gas and air. The tests now under way will determine the factor of safety of such lamps as have not caused ignition in previous experiments.

In making tests of incandescent lamps they are placed in a gas-tight receptacle filled with a mixture of gas and air combined in proportions most sensitive to ignition. The lamps are lighted and the filaments are brought into contact with the gaseous mixture in three ways, as follows:

(*a*) By smashing the bulbs completely, which brings the mixture in contact with broken filaments.

(*b*) By snipping off the tips, which usually does not break the filaments as the velocity of the entering gas is less than in (*a*).

(*c*) By puncturing a small hole in the necks of the bulbs, which prevents the entering gas from impinging directly upon the filaments and therefore rarely breaks them.

Such lamps as do not ignite the mixtures under normal conditions are further tested by increasing the temperature of their filaments until explosion follows the breaking of the lamps. A comparison of the excess energy required in any case gives a good indication of the relative safety of the lamp.

In addition to making these lamp tests, the bureau is investigating explosion-proof motors, explosion-proof switches, and the action of mine water upon the insulation of electric conductors.

TESTS OF EXPLOSION-PROOF APPARATUS.

Explosion-proof switches and explosion-proof motors are tested in the same way, as the flame-proof quality of the casings is in each case the point at issue.

The term "explosion-proof," as applied by the Bureau of Mines to electrical equipment, refers to apparatus inclosed in casings that are so designed and constructed that the products of explosion resulting from the ignition, within the casing, of any mixture of methane and air will be either entirely confined within the casing or so discharged from it that they can not ignite a mixture of methane and air, combined in proportions most sensitive to ignition, entirely surrounding the casing and in intimate contact therewith.

In testing explosion-proof apparatus the casings are completely filled with various mixtures of gas and air and completely surrounded by a mixture of the same constituents combined in proportions most sensitive to ignition. The mixture within the casing is exploded by an electric spark, and the character and extent of the discharged flames, and their action upon the surrounding gas are noted.

Means are provided for measuring the pressure developed within the casings by the explosions.

TESTS OF INSULATION OF ELECTRICAL CONDUCTORS.

The present investigation of the action of acid mine waters upon the insulation of electrical conductors is preliminary in character, having for its purpose the standardization of methods for future tests. The results of this investigation will determine the character of the waters to be used, the best way to apply them to the insulation, and the most satisfactory methods of observing the action of the water upon the material under test.

In the present test two kinds of water are being used. These are being applied in three different ways to three different kinds of insulations, of each of which there are 10 samples 50 feet in length. The action of the water upon the insulation is being observed by means of insulation resistance measurements and by high potential tests.

OTHER INVESTIGATIONS.

Preparations are now being made to investigate the action of electric sparks and arcs in coal dust.

Among other investigations to be undertaken as soon as possible are an investigation of the danger of using electricity in the vicinity of explosives, an investigation of electrical shot-firing devices, and a study of devices for the protection of the trolley wire.

TESTS OF INCLOSED CARTRIDGE FUSES IN EXPLOSIVE GAS.

As a part of the investigation of the causes of mine explosions, authorized by Congress in May, 1908, the Secretary of the Interior decided that a careful examination should be made of the various inclosed electric fuses used in mining operations with a view to determining how far these fuses, when installed for service in gaseous atmospheres, might be responsible for the occurrence of disasters.

CONDITIONS OF TESTS.

With this in view, a letter was sent by the Director of the United States Geological Survey on July 8, 1909, to the manufacturers of fuses in the United States, setting forth the conditions under which such fuses would be examined and the nature of the tests to which they would be subjected. This letter stated the number and capacity of the fuses desired and outlined the following conditions under which manufacturers could submit fuses for test:

The material submitted should be the standard product of the manufacturer and similar in every respect to that offered for sale in the open market.

Manufacturers should deliver the required fuses, together with suitable mountings, at the testing station at Pittsburg, Pa.

No one was to be present or to participate in the tests other than the necessary Government officers at the testing station, and their assistants, except that a representative of the manufacturer of the material to be tested might be present if he so elected.

The tests were to be made in the order of the receipt of the applications for them, provided the necessary quantity of material was delivered at the station by the time assigned, and the manufacturers were to be notified far enough in advance to allow a representative to be present at the tests.

No test of material not on the market would be made until all the fuses offered in response to this letter had been tested.

A list of fuses which passed certain requirements would be supplied to State mine inspectors and made public in such other manner as might be considered desirable.

ELECTRICAL FUSES TESTED.

In response to the above communication, applications were received from seven different manufacturers, who submitted samples of their product for test.

The fuses tested were standard N. E. C. cartridge fuses of the indicator type, varying in size from 30 amperes, 250 volts, to 100 amperes, 600 volts.

There are two elements of danger attending the action of such fuses in the presence of inflammable mixtures of gas and air, namely: (*a*) The action of the indicators located on the external surface of the shell; these when the fuse acts may, by giving out sparks or otherwise, ignite the explosive mixture; (*b*) the blowing of hot gas and jets of flame through the relief ports of the fuses by the energy released within the shell.

The generating capacity available for making the tests was sufficient to test only the indicators of the fuses to a satisfactory limit. Although, therefore, the tests proved the dangerous character of the indicators, they can not be considered conclusive as to the safety of the relief ports. The available generating capacity also limited the tests to fuses having a capacity of 100 amperes or less in both 250 and 600-volt sizes. The conditions were about as severe as those in a large percentage of the mine installations of the present day.

Seven different brands of fuses were tested. They are referred to in this report as "Brand No. 1," "Brand No. 2," etc. Each brand differed slightly from the others in the design of its indicator, although all made use of a fine wire which was burnt off when the fuse acted. The details of the indicator devices are given below:

Brand No. 1.—The indicating wire of this brand was led through a pinch of inflammable powder placed upon the outer surface of the shell and covered by a paper label. When the fuse acted the burning of the indicator wire ignited the powder, which burned a hole in the paper.

Brand No. 2.—The indicator of this brand was similar to that of brand No. 1, but had more powder under the paper label.

Brand No. 3.—The indicating wire of this brand was led across a circular white paper dot placed upon the outer surface of the shell. The wire was covered by a paper label except where it crossed the dot. When the fuse acted the wire burned off and left the dot clear.

Brand No. 4.—The indicator of this brand was similar to that of brand No. 3, but the indicator wire was led under the paper dot which, when the fuse acted, burned and exposed the shell of the fuse.

Brand No. 5.—The indicating wire of this brand was led through a small quantity of inflammable material held in a little hole in one of the brass caps. When the fuse acted this material burned and left a black spot upon the brass cap.

Brand No. 6.—The indicating wire of this brand was led through an explosive wad sunk into the fuse shell and covered by wire gauze and a disk of leather or similar material. When the fuse acted the disk was blown out of place.

Brand No. 7.—This brand had two types of indicators, both of which depended upon the action of a spring released by the burning of the indicator wire.

The fuses were mounted in standard clips or holders and placed inside a gas-tight, boiler-iron box that measured 24 by 18 by 18 inches. This box was provided with means for admitting any desired percentage of gas. The electrical connections were so made that by throwing a single switch the full potential of 250 or 600 volts was thrown directly across two fuses in series.

GENERATORS.

Four different generators or combinations of generators were used. They are designated below as Nos. 1, 2, 3, and 4.

Generator No. 1 was a 35-kilowatt direct-current machine designed to give any voltage up to 350 volts. It was direct connected to a 53-horsepower 220-volt direct-current motor operated from a 150-kilowatt generator located in the power station about 450 feet away. Through 350 feet of this distance power was carried on No. 4 (B. & S.) cables, the remainder of the line being No. 2 (B. & S.) wire. The connections from generator to fuses were about 120 feet (both sides) of miscellaneous copper switches, circuit breakers, etc., averaging about No. 4 (B. & S.).

Generator No. 2 was a 150-kilowatt, 250-volt machine belted to a gas engine and sending power over the lines above described.

Generator No. 3 consisted of two 100-kilowatt, 250-volt generators driven by a De Laval steam turbine and operating in multiple. Power was delivered over the lines described.

Generator No. 4 was a combination of generator No. 2 and the two machines of generator No. 3, all operating in series and each generating 200 volts. The power lines were the same.

RESULTS OF TESTS.

The results of the tests are summarized in the following table:

Results of tests of inclosed cartridge fuses.

Brand No.	Number of tests	Number of explosions.	Cause of explosion.			Percentages of explosions.
			Undetermined.	Indicator.	Blowing at port.	
1	24	10	1	3	6	41.6
2	23	12	.....	12	.....	52.2
3	32	24	.....	24	.....	75.0
4	24	5	.....	5	.....	20.8
5	20	13	.....	13	.....	65 0
6	21	1	.....	.....	1	4.75
7	32	1	.....	1	.....	3 125

CONCLUSIONS.

The conclusions obtained from the results of these tests are as follows:

1. One or more sizes of all the brands of fuses tested ignited the gas, although in varying degrees. Two brands ignited the gas but once; three brands ignited it in more than 50 per cent of the trials.

2. The principal source of danger in fuses as they are now designed is the device for indicating whether or not a fuse has acted.

3. Danger from blowing at the relief ports will probably develop in some and possibly in all brands if tested with enough generating capacity.

PUBLICATIONS ON MINE ACCIDENTS AND EXPLOSIVES.

The following publications, except those to which a price is affixed, may be obtained free by applying to the Director, Bureau of Mines, Washington, D. C. The priced publications can be obtained by sending the price, in cash, to the Superintendent of Documents, Government Printing Office, Washington, D. C.

PUBLICATIONS OF THE BUREAU OF MINES.

MINERS' CIRCULAR 2. Permissible explosives tested prior to January 1, 1911, and precautions to be taken in their use, by Clarence Hall. 1911. 12 pp.

MINERS' CIRCULAR 3. Coal-dust explosions, by George S. Rice. 1911. 22 pp.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

BULLETIN 333. Coal-mine accidents: Their causes and prevention; a preliminary statistical report, by Clarence Hall and W. O. Snelling, with introduction by J. A. Holmes. 1907. 21 pp. 5 cents.

BULLETIN 369. Prevention of mine explosions, report and recommendations, by Victor Watteyne, Carl Meissner, and Arthur Desborough. 1908. 11 pp. 5 cents.

BULLETIN 383. Notes on explosive mine gases and dusts, with special reference to explosions in the Monongah, Darr, and Naomi coal mines, by R. T. Chamberlin. 1909. 67 pp.

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